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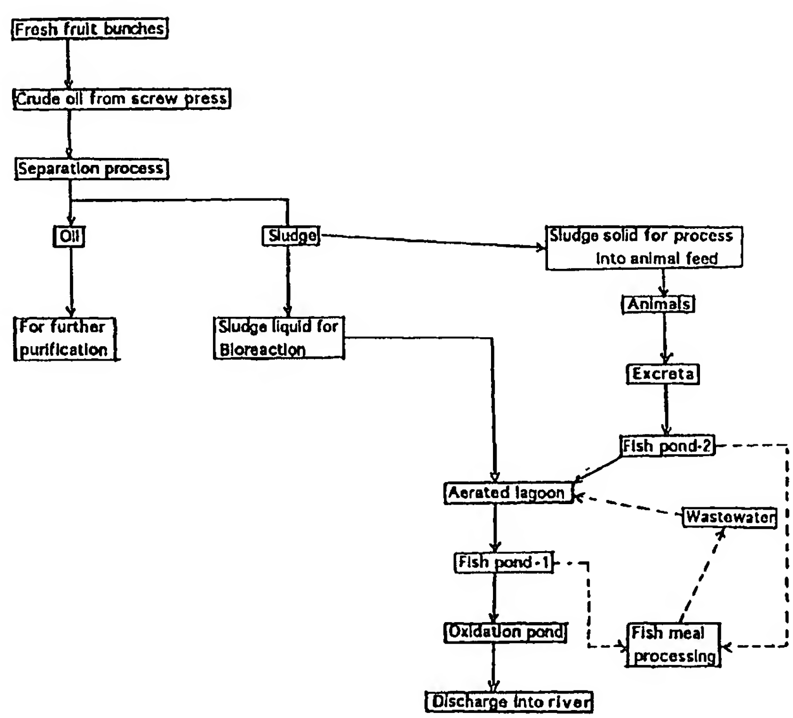
(54) Title: SYSTEM FOR TREATING PALM OIL MILL EFFLUENT

(57) Abstract

A system for the treatment of palm oil mill effluent which utilizes different organisms for bioremediation at different stages of the treatment process. The method allows the oil palm mill by-product to enter a complete food chain, with production of high-value fish protein as an end product. The crude oil, obtained from the pressing of the sterilized fresh fruit bunches, is separated into oil and sludge followed by the separation of the sludge into sludge solid and sludge liquor. The sludge solid is first treated by digestion in animals to form animal excreta. The excreta is then converted to microorganic biomass in an aerated pond or fed to fishes directly. The biomass is then converted to high-value protein product by feeding the biomass to fishes in one or more fish ponds. The sludge liquor is first converted to microorganic biomass by microorganic digestion, preferably in a bioreactor. The biomass is then converted high-value fish product by feeding the effluent of the bioreactor to fishes in the fish pond. The effluent from the fish pond may be further treated to meet effluent requirements before being discharged into the environment.



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SYSTEM FOR TREATING PALM OIL MILL EFFLUENT

FIELD OF THE INVENTION

The present invention is related to bioremediation. In particular, the present invention is related to the bioremediation of waste products from palm trees and palm oil production.

BACKGROUND OF THE INVENTION

Palm oil is an important product in tropical areas where palm trees grow readily. Palm oil production typically involves the separation of the fresh fruits bunches from the vegetative material, followed by sterilizing, threshing, digesting and pressing of the fruits to produce crude oil. The oil is then separated from the aqueous and particulate portions and further purified. The remaining waste aqueous and particulate portion, generally known as sludge, has a very high Biochemical Oxygen Demand (BOD) content, which may be several orders of magnitude higher than that allowed for discharge into rivers. Furthermore, the sludge has a high oil content which is difficult to treat and digest. The Proceedings Of The Workshop On Review of Palm Oil Mill Effluent Technology (1984) published by the Palm Oil Research Institute of Malaysia (PORIM) contains detailed description of current methods of treatment of palm oil mill effluent which are summarized below.

The bioremediation process typically includes an anaerobic phase and an aerobic phase. The anaerobic phase generally utilizes acidification

bacteria, which break down the oily waste into soluble fatty acids. The solubilised hydrocarbon and other organic substances can then be further digested in the aerobic phase by aerobic bacteria, which further reduces the BOD of the waste sludge. In some systems, an additional anaerobic phase is included after the acidification phase, wherein methanogenic bacteria converts the organic waste into biogas.

Systems used for the aforementioned bioremediation have certain drawbacks. In the anaerobic digestion method to produce biogas, the methane-generating process requires a closed tank for gas collection and to maintain the methane bacteria, which are strict anaerobes. Although this system is useful in generating usable biogas, capital investment, operating costs and maintenance costs are high, and the bacteria is very sensitive to changes in loading, pH and temperature. The biogas generated may be used for generating electricity, but this would require additional equipment for the energy conversion to occur. In addition, desulfur equipment may also be required to extend the life span of the boiler used for steam generation if a high content of sulfide gas is found in the biogas. Further equipment costs would have to be incurred if the electricity generated is to be distributed to the end users.

In the widely used ponding system, various ponds are used for the bioremediation process. These include anaerobic pond for the bacterial conversion of oily substances to fatty acids and the conversion to methane and carbon dioxide; facultative ponds for further anaerobic and aerobic digestion of both organic and oily substances; and oxidation ponds for aerobic purification of residual organic substances. The capital cost of this

system is low but land requirement is extremely high. The time which is required for treatment is also very high, further increasing the space requirement, since large ponds must be used to hold the large quantity of waste effluent for bioremediation, before discharging into the environment.

In the decanter system, the bulk of the oily portion of the crude oil is separated from the sludge by centrifugation. This method minimizes the volume of sludge that is generated, such that drying of the sludge by evaporation becomes feasible. As a result, the amount of polluting effluent generated is minimized. The equipment cost for this system, however, is very high, and machinery rather delicate. This is particularly important due to the high sand content of the crude oil, which accelerates the wearing rate of the delicate machines.

The solid sludge that is derived from the systems mentioned above are typically used as fertilizers in the palm plantation or as feed for livestock such as cattle, swine and poultry. The use of the sludge solids as fertilizers, however, is beneficial only if the oil content of the sludge solid has been reduced to an acceptable level. Furthermore, transportation, distribution and handling of the large amounts of sludge presents an additional burden on the resources of the oil palm. If the sludge solids are used as feed, the moisture content must be kept at a low level, such as below 7%, in order to prevent molding during storage. This is necessary because the livestock farms are typically separate entities from the palm oil plantations, with their own waste disposal procedures. Therefore, even if the moisture level of the sludge solid can be maintained below 7%, a

proper infrastructure must be present to transfer the sludge solid to the livestock farms.

OBJECT OF THE INVENTION

It is therefore an object of the present invention to provide a treatment system for palm oil mill effluent to overcome the shortcomings as stated above.

It is another object to provide a low cost bioremediation system.

It is a further object to provide a low emission treatment system for palm oil mill by-products.

SUMMARY OF THE INVENTION

The present invention is a system for the treatment of palm oil mill effluent which utilizes different organisms for bioremediation at different stages of the treatment process. The system allows the oil palm mill by-products to enter a complete food chain, with production of high-value fish protein as an end product. The crude oil, obtained from the pressing of the sterilized fresh fruit bunches, is separated into oil and sludge followed by the separation of the sludge into sludge solid and sludge liquor. In the preferred embodiment, the sludge solid is first treated by digestion in animals to form animal excreta. The solid in the excreta is diverted to a fish pond for breeding of fish such as the polyphagous Swai, *Pungasius sutchi*. The liquid portion of the excreta is converted to micro-organic biomass in an aerated lagoon. This micro-organic biomass is then converted to high-value protein product by feeding the biomass to fishes

in one or more fish ponds. In a further aspect of this preferred embodiment, the sludge liquor is first converted to micro-organic biomass by micro-organic digestion. This may involve the use of a bioreactor, for example, for fungi or bacterial production, or any other biochemical means which is able to maintain conditions for micro-organic growth. In the most preferred embodiment, the effluent from the biological digestion of the sludge liquor is further discharged into an aerated lagoon, where the fungi or bacteria is consumed by other micro-organisms such as protozoa.

The biomass from the aerated lagoon is then converted high-value fish product by feeding the effluent to fishes. The effluent from the fish pond, often containing a BOD level of more than 60mg/L, may be further treated to meet effluent requirements before being discharged into the environment. Oxidation pond is a preferred and economical treatment process for dealing with effluent having comparatively lower BOD and nutrient levels, which can be converted to bacteria and photosynthetic algae. The treated effluent can then be safely released into the environment. The solid arrows in Figure 1 shows this embodiment of the present invention. In this example, there are two types of fish ponds. Fish pond-1, which received effluence from the aerated lagoon, preferably contain zooplankton feeding fishes such as tilapia or young Swai. Fish pond-2, which receives solid excreta from animal farming, preferably contain polyphagia fishes such as swai, since the adult swai is known to feed well on solid excreta.

Additional waste effluent generated by the palm oil mill, such as septic tank effluent and waste water from fish meal processing and empty fruit

bunch processing, may also be channeled into the aerated lagoons for biomass production followed by conversion into fish protein. The short dotted arrows in Figure 1 shows the process of how water used for fish meal production may also be channeled into the aerated lagoons for micro-organic biomass production before being recycled back into the fish pond.

Figure 2 shows another embodiment of the present invention in which the vegetative by-products of the palm plantation, namely the empty fruit bunches, may also be utilized in an environmentally clean process. In this embodiment, the processes as shown by the solid arrows and short dotted arrows are the same as those in Figure 1. The long-short dotted arrows show how the empty fruit bunches may be pressed to produce liquor, and the remaining fibrous material rinsed with water. The pressed liquor and waste water which is collected from the rinsing process may be discharged into the aerated lagoon for micro-organic biomass production. The washed fiber may be useful as raw materials such as soil conditioner for sports grounds and young shoot protection mat, as well as raw material in the production of cellulose. Alternatively, the washed fiber, which now have substantially reduced levels of organic waste, may be used as a clean boiler fuel.

Figure 3 shows a further embodiment of the present invention in which all the by-products of palm oil mill production are treated or utilized such that any effluent finally released into the environment would comply with environmental regulations.

Using the biological treatment system described above, not only can the palm oil mill effluent be made environmentally safe, but the BOD content can also be converted to high-value fish biomass which can ultimately generate profit to pay for the bioremediation system.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram to show one bioremediation system according to the present invention.

Figure 2 is a schematic diagram to show another bioremediation system according to the present invention.

Figure 3 is a schematic diagram to show yet another bioremediation system according to the present invention.

Figure 4 is a schematic diagram to show the possible sources of effluent for discharge into the aerated lagoon according to another aspect of the present invention.

DESCRIPTION OF THE INVENTION

The present invention is a system for palm oil mill effluent which is capable of achieving low or even zero emission to the environment. In Malaysia, the BOD requirements by the Department of Environment for discharging waste water are 20mg/L or less in urban areas and 50mg/L or less in rural areas. To achieve these low BOD levels, a bioremediation system using different organisms, including plants, animals and micro-organic biomass is described. As used herein, microorganisms and micro-organic biomass refer to fungi, bacteria, algae, protozoa or rotifers, or a combination thereof.

Figures 1-3 shows various embodiments of the present invention in which the various waste products from palm oil production is treated and utilized effectively. The main waste product which contain high BOD content is the sludge (which contains solid mixed with fruit liquor) remaining after removal of the palm pericarp in the pressed digesting fresh fruit bunches. The oil may be removed by any conventional methods, such as by continuous clarification. In the clarification tank, the primary oil is separated from the mixture of solid and fruit liquor, and sent to the oil drier through the purifier. The remaining mixture, consisting of fruit liquid, solid and residual (secondary) oil, is sent to the sludge tank. The secondary oil and the fruit liquor are recovered separately, and the solid is allowed to settle to the bottom of the tank as sludge solid.

Bioremediation of sludge liquor

After the useful oil is removed from the crude oil, the remaining portion is sludge, which may contains 1,000 to more than 10,000 mg/L of suspended solid. The sludge liquor typically contains high levels of oil and grease, such as n-hexane extract, in addition to extremely high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Table 1 shows the analytical results of a sample of palm oil mill effluent obtained in a palm oil plant. Analysis was performed on a sample of sludge (i.e. fruit liquor mixed with solid) taken at the inlet pit of the sludge tank. This sample had COD, BOD_5 and n-hexane extract concentration of 49,300 mg/L, 272,000 mg/L and 7,090 mg/L respectively, and falls within the range of effluent content reported in the 1980/1981 PORIM/PPIM survey by A. Maheswaran, in *the Proceedings of the workshop on review of palm oil mill effluent technology,* pp.1-10, 1984. The sludge was calculated to contain 42% oils, 7% proteins and 51% unknown substances containing carbohydrates on the basis of COD. When oils are represented as $C_3H_5(COOH)_3$, 1 mg/L of oil is converted to 2.9mg/L of COD. 63% of total COD was solids and most of them were oils. Since the ratio of BOD to COD was 0.55, which is comparable with that found in sewage, the palm oil mill effluent was presumed to be oxidized biologically. The ratio of COD to N and P was 100:1.2:0.3.

	Total (mg/L)	Dissolved (mg/L)
CODcr	49,300	18,200
BOD_5	27,200	11,000
TOC	11,300	5,070
S S	12,700	
n-hexane extracts	7,090	
Total nitrogen	576	(pH 3.60)
Total phosphate	140	

TABLE 1

It is well known that biological treatment using yeast reactor is efficient for the treatment of waste water from food processing, which contains extremely high concentrate of BOD_5 (e.g. over 10,000mg/L) and high fatty/oily material (e.g. over 1,000mg/L), such as described by Chigusa et al. in the article "High rate performance and characteristics of food processing wastewater treatment using yeast" in *Proc. of Environmental Engineering Research, Japan Society for Civil Engineers*, vol 32, p89-97 (1995), and incorporated herein by reference. According to this study, yeast treatment using three yeast strains (Candida edax, Trichosporiella flavificans and Trichosporon capitatum) was suitable for processing wastewater which consists of high concentration of organic matter

(2,100mg/L or higher of BOD, 3,400mg/L or higher of COD) and oil (280mg/L or higher as n-hexane extracts). The digestion of organic matter by yeast was good when the wastewater was kept at 30-40°C and pH of 4-6. Furthermore, better results were obtained at 0.5 to 1.2kg•BOD/kg•yeast•day as Food/microorganism ratio and at 0.07 to 0.18kg•n-hexane-extract/kg•yeast•day.. The removal of COD, lipid, protein, amino acid, carbohydrate and volatile fatty acid were approximately 91%, 98%, 91%, 59%, 89% and 96% respectively. The effluent of BOD by yeast treatment was maintained usually at approx. 120mg/L of BOD_5. According to the study by Ms Chigusa et al., of wastewater from food processing using yeast, the nutrient balances were approx. BOD:N:P = 100:4~5:1. As the average ratio of COD/BOD was 160/100, it is expressed as COD:N:P=100:2.5~3:0.6. Therefore, a COD:N:P ratio of 100:1.2:0.3 as found in the sludge described above may be treated using conditions similar to the Chigusa process, for example by addition phosphorus and nitrogen supplements to the culture broth in the form of phosphoric acid and anhydrous ammonia.

Other processes, for example using bacteria, may also be used for the micro-organic digestion of the sludge liquor, as suggested by van Soest et al. in "Tertiary Treatment Quality For A Secondary System Utilizing the Zum-Attisholz Process", in the *Proceedings of the 28th Purdue Industrial Waste Conference*, Purdue University, Lafayette, Ind. USA (1973), and incorporated herein by reference. According to van Soest et al., another way be treating the waste liquor is to use a two-stage process, in which the liquor is first digested in a mixed culture of predominantly bacteria and

lower fungi, followed by the discharge into aerated lagoons. which contains a culture of predominantly protozoa. The first stage bacteria and lower fungi may form dispersed growth, which can be carried over to the second stage, and be readily consumed as food by the protozoa. According to the present invention, this two stage process can also be exploited as an intermediate step in the overall bioremediation process, in which the sludge liquor is converted to micro-organic biomass.

Other biochemical engineering or biological systems known in the art may be used if they are able to digest organic waste of the type found in palm oil mill effluent and in addition be channeled into fish ponds as a source of nutrient for fishes.

BIOREMEDIATION OF SLUDGE SOLID

The sludge solids obtained after removal of the sludge liquor are typically used as fertilizer or animal feed by conventional palm oil mills. This is a well-documented process, as described by PORIM, *supra*. According to one aspect of the present invention, the use of the sludge solid as an animal feed may be used as an intermediate step in the bioremediation process. In this aspect, the untreated sludge solid, which may have a moisture content of approx. 80% percent, can be fed to livestock such as chicken, swine or cattle. On-site breeding is preferred, as it provides convenience by reducing transportation and storage requirements. This is an important advantage, as feed with such a high moisture content would otherwise be difficult to store and transport. With

an on-site farm, the solids can be consumed by the animals with minimum transition time, making the sludge solid a healthier and more viable animal feed. Depending on the type of animal used (e.g. cattle, chicken or swine) in this bioremediation step and the purpose for raising them (e.g. for milk, meat or eggs), various food supplements well known in the art may be used to raise productivity. For example, if chickens are raised for egg production, carotene and other vitamins may be added. Cattle is the preferred livestock, since they are herbivorous ruminants with digestive systems well adapted to digestion of materials found in the sludge solid. The excreta from the animal is then further separated into the liquid part and the solid part in the livestock house. The liquid part is sent to the aerated lagoon for biomass production and bioremediation as discussed in the following section, while the solid part is sent directly to fish pond-2 as feed for polyphagous fishes such as swai.

BIOREMEDIATION BY AEROBIC LAGOON

The aerobic or aerated lagoon is a crucial intermediate step in the bioremediation process. As shown in Figure 5, the aerated lagoon in the most preferred embodiment is designed to receive effluent from numerous sources, including pressed liquor from the sterilized empty bunch, effluent from bioreaction, effluent from fish pond-2, which may contain residual solid excreta, liquid animal excreta, septic tank effluent and waste water from fish meal processing.

The aerated lagoon may be one or more ponds which are equipped with aerating means such as mechanical aerators, and contain dispersed aerobic bacteria, protozoa and rotifers. The aerating means ensure sufficient oxygen supply to the aerobic bacteria to grow on the organic waste, and results in the production of micro-organic biomass (the aerobic bacteria), with the reduction of BOD and COD. The presence of significant levels of protozoa and rotifers, such as water fleas, vorticella, carchesium and amoeba, which feed on bacteria and yeast, allows bacteria and lower fungi biomass to be converted to multicellular or more complex biomass. The protozoa, which are about 1,000 times larger than bacteria and fungi, are readily taken as feed by many species of fishes.

BOD removal in the aerated lagoon and their designs are known in the art, for example, as described by D. Mara in *Sewage Treatment in Hot Climates*, published by John Wiley & Sons, 1976, and incorporated herein by reference.

The basic relationship may be approximated as a first order equation as follows :

$$L_e = L_i \cdot (1+K_1 \cdot t^*)^{-1} \quad \text{———} \quad (1)$$

Where L_e and L_i are BOD_5 (mg/L) of effluent and influent respectively, K_1 is the first order rate constant (d^{-1}), and t^* is the retention time (d).

L_e is due to two separate factors : 1) the small amount of influent waste (BOD_5) which is not oxidized in the aerated lagoon, and 2) bacteria cells

being generated during oxidation, These factors are generally referred to as the "soluble" and "insoluble" BOD_5 respectively.

The soluble BOD_5 in the effluent, F_e(mg/L), is expressed as first order kinetics as follows :

$$F_e = L_i \cdot (1 + \kappa \cdot t^*)^{-1} \quad \text{———————} \; (2)$$

where κ is the first order rate constant for soluble BOD_5 removal (d^{-1}) and the typical value is $5d^{-1}$ at 20°C. Its value at other temperatures (T°C) can be estimated from the following equation :

$$\kappa_T = 5 \cdot (1.035)^{T-20} \quad \text{———————} \; (3)$$

The quantity of bacteria synthesized in the aerated lagoon is related to the quantity of soluble BOD_5 oxidized. The rate of cell synthesis is balanced by the sum of the rate at which the cells leave the lagoon in the effluent and the rate at which they die in the lagoon. That is, the rate of synthesis as the sum of the rate of autolysis and the rate of loss in effluent is expressed as :

$$Y\,(L_i - F_e)\,V \cdot t^{*-1} = bXV + QX \quad \text{———————} \; (4)$$

where X is cell concentration in the lagoon (mg/L), Y is yield coefficient, typically 0.6-0.7, F is soluble BOD (mg/L), and V is lagoon volume (m^3).

The rate at which the cells leave the lagoon is QX where Q is the flow through the lagoon. The rate at which some of the cells in the lagoon die is proportional to the quantity of the cell present; it is usually given as bXV where b is the rate autolysis (d^{-1}), typically $b=0.07d^{-1}$.

Rearranging equation (4) and substituting V/Q with t*,

$$X = Y\,(L_i - F_e) \cdot (1+bt^*)^{-1} \quad \text{------------} \quad (5)$$

This quantity of cells X can be converted to an equivalent ultimate BOD by considering the chemical equation for their complete oxidation :

$$C_5H_7NO_2 + 5O_2 = 5\,CO_2 + 2H_2O + NH_3 \quad \text{------------} \quad (6)$$

Thus 1g of cells has an ultimate BOD of (5X32/113) = 1.42g. Since $BOD_5/BOD_{ultimate}$=2/3, 1g of cells has a BOD_5 of 0.95g. Thus the effluent BOD_5, L_e, is given by :

$$L_e = F_e + 0.95X \quad \text{------------} \quad (7)$$

Therefore, for an influent BOD_5 of 600mg/L, with t*=5d, T=26.5°C, and κ_T=6.25d^{-1} at 26.5°C as derived from eqn. (3), and assuming b=0.07d^{-1} and Y=0.65, equations (2), (5) and (7) give :

$$F_e = L_i \cdot (1+\kappa \cdot t^*)^{-1} = 600 \cdot (1 + 6.25 \times 5)^{-1} = 18.6 \text{ mg/L}$$

$$X = Y\,(L_i - F_e) \cdot (1+bt^*)^{-1} = 0.65\,(600 - 18.6) \cdot (1 + 0.07 \times 5)^{-1} = 280 \text{ mg/L}$$

$$L_e = F_e + 0.95X = 18.6 + (0.95 \times 280) = 284.6 \text{ mg/L}$$

Thus the BOD_5 of the lagoon effluent, L_e, is approx. 285 mg/L, but 90% of this is due to the bacteria present. If these bacteria (or most of them) are removed from the effluent, the BOD_5 will be considerably reduced. In general, effluent with soluble BOD_5 of less than 75mg/L may be discharged into the fish ponds. If the BOD_5 exceeds 75mg/L, the effluent

may be diluted before being discharged into the fish pond in order to maintain a sufficient oxygen level.

In addition to animal excreta, other organic effluent may also be discharged into this aerated lagoon for biomass generation, such as septic tank effluent and waste water from the various washing processes, as shown in Figure 4. Furthermore, algae, which grow naturally in the pond where considerable quantities of both nutrients and incident light energy are available, may also be grown as a source of food for the fishes. After oxidation, the effluent may be discharged, together with the biomass, into the fish pond.

PRODUCTION OF HIGH-VALUE FISH PROTEIN FROM BIOMASS

Fish cultivation technique which uses fishes as a natural part of the food chain has been widely used in various countries. For example, in Thailand, farmers raise swine using rice bran recovered after the rice polishing process as a feed for the swine. The swine excreta is in turn sent to fish ponds, where fishes such as Swai, are well-known feeders of excreta directly.

In accordance with the present invention, the waste generated from animal production is further converted to high value fish protein via an intermediate step of microbial bioconversion as described in the previous section. Both the liquid and the solid portions of the excreta may be

discharged into the oxidation lagoon for bioremediation into bacterial biomass. In the preferred embodiment, the waste product from the animals is separated into the solid and liquid portions. The solid portions may be directly discharged into fish ponds stocked with fish types which thrives on the solid excreta, such as the Swai fish. The liquid portion of the excreta may be discharged into the oxidation lagoon for bioremediation and biomass production. When the soluble BOD of the aerated lagoon is within a safe level, the effluent may be discharged into one or more fish ponds stocked with fishes such as tilapia, which are well-known feeders of microorganisms, including fungi, protozoa, and bacteria. The acceptable level of soluble BOD before discharge depends on the fish type, and may be determined empirically by one in the art. In the preferred embodiment, soluble BOD should be below 50mg/L. The fish can then be consumed by the people as a high-value protein source. In addition, the fishes may be processed into fish meal for domestic or foreign consumption.

The system according to the present invention uses not only bacterial biomass generated from excreta and other waste effluent, but also fungal biomass such as yeast which may be generated from the bioconversion from the sludge liquor. Other micro-organism such as protozoa in the aerated lagoon may also be produced in this bioconversion. The micro-organic biomass is a good source of nutrient for the fish. Besides tilapia, other fishes which thrive on micro-organic biomass may be used, and the species determined based on the fauna in the location where the present invention will be practiced, using the teaching described herein. The fish

is one step of the food chain, but is important since it is able to convert low-value biomass into high-value protein.

When the fish is harvested and processed, additional waste water may be generated. These can be fed back to the aerobic lagoon for further biomass generation, thereby complete the recycling process. Examples of how the various bioremediation steps are used in the present invention as described above are shown in Figures 1-3.

BIOREMEDIATION IN OXIDATION POND

The oxidation pond described herein is similar to the maturation ponds used in waste stabilization wherein entirely natural processes involving both algae and bacteria are utilized. This is a recommended step in the entire bioremediation process if the effluent of the fish ponds and the waste water generated during the process of fish meal processing mentioned above cannot be discharged into the environment directly, due to, for example, high BOD.

The main function of the oxidation pond is the destruction of pathogens. Fecal bacteria and viruses die off reasonably quickly owing to what is to them an inhospitable environment inside the oxidation pond. The cyst and ova of intestinal parasites have a relative density of 1.1 and as a result settle to the bottom of the pond under sufficiently long retention time, whereupon they eventually die. The oxidation ponds are completely aerobic and are able to maintain aerobic conditions at depths of up to 3m.

In one embodiment, two ponds used in series, each with a retention of 7 days, is able to reduce the BOD_5 from 50-70mg/L to less than 25mg/L. The effectiveness of the oxidation ponds in pathogen removal may be conveniently assessed by the removal of fecal coliforms. Various pond designs are discuss by D. Mara, supra, and by Osward and Gotaas in *Transactions, American Society of Civil Engineers*, Paper No. 2849, pp. 73-105 (1955). With the proper design, pathogen removal of greater than 99.99% can be achieved.

As an example, the design of the oxidation mode may be carried out by applying first order kinetics to the reduction of fecal bacteria as follows :

$$N_e = N_i \cdot (1+K_b t^*_1)^{-1} (1 + K_b t^*_2)^{-1} \quad \text{———} \quad (8)$$

where N_e is the number of fecal coliform per 100ml of effluent, Ni is the number of fecal coliform per 100ml of influent, K_b is the first order rate constant for fecal coliform removal (d^{-1}) and $t^*_{1 \text{ or } 2}$ is retention time in the first or second pond (d).

K_b is extremely temperature sensitive, and is given by the equation :

$$K_{b(T)} = 2.6\ (1.19)^{T-20} \quad \text{———} \quad (9)$$

where the value of K_b is at the temperature of T°C.

Another use of the oxidation pond is for the growth of algae, which grow naturally in ponds where considerable quantities of both nutrient and incident light energy are available. This also encourages a symbiotic relationship, in which the microorganisms in the pond utilize the oxygen

produced by the algae to oxidize the organic waste matter. The carbon dioxide produced as the major end-product of bacterial metabolism is then taken up by the algae during photosynthesis, since their demand for it exceeds what can be supplied from the atmosphere. It has been known that the algae grown in a high-rate pond yield 82,000kg/ha•yr as protein, against 650kg/ha•yr of soybean and 55kg/ha•yr of rice. The algae is also a rich source of protein which can be utilized by humans or animals.

BIOREMEDIATION AND UTILIZATION OF EMPTY FRUIT BUNCHES

For every 100 tons of fresh fruit bunches processed, there is approximately 25 tons of empty bunches which require treatment and/or disposal. The traditional way of incineration of the vegetative waste produces air pollution. The other conventional disposal method, dumping, is insanitary and costly.

Figures 2 and 3 show two embodiments of the present invention in which empty fruit bunches are further processed and utilized in an environmentally safe manner. According to this aspect of the present invention, the empty bunches are first sliced and pressed to remove the liquid. The remaining fibers are then washed to remove organic waste. The pressed fiber liquor and waste water from this washing process (hereinafter referred to as fiber effluent) may be discharged into the aerobic lagoon for biomass generation, as shown by the long dotted arrows in Fig.2. The washed fibers may then be incinerated without any

smoke emission, and the ash recovered as a rich potassium and phosphorous fertilizer. Altematively, the fibers may be used as a ground or roof cover in the conventional manner.

As an example, as shown in the long dotted arrows in Figure 2, at a 30 tons per hour processing mill, roughly 7 tons per hour of empty bunches are produced. If the ration of liquid to solid is 7:3, then liquid production is 4.9 tons per hour (39.2 tons per day) and solid production is 2.1 tons per hour (16.8 tons per day for an 8-hour per day operation). Approximately 50 cu meter of rinsing water is required for washing (i.e. fiber effluent), which would be discharged into the aerated lagoon together with the pressed liquor. This rinse water may come from the oxidation pond.

While the present invention has been described particularly with references to Figs 1 to 4, it should be understood that the figures are for illustration only and should not be taken as limitation on the invention. In addition it is clear that the biological system of the present invention has utility in other types of plantation where effluent is produced. It is contemplated that many changes and modifications may be made by one of ordinary skill in the art without departing from the spirit and the scope of the invention described.

CLAIMS

1. A method for treating palm oil mill effluent comprising :

pressing said palm fruits to produce crude oil and empty fruit bunches

separating the crude oil into palm oil and sludge;

separating the sludge into sludge solid and sludge liquor;

feeding animals with the sludge solid;

producing micro-organic biomass from the sludge liquor; and

feeding fishes in at least one fish pond with said micro-organic biomass.

2. A method according to claim 1 further comprising the steps of

pressing said empty fruit bunches to produce fiber liquor and fibers;

rinsing said fibers with water to produce fiber effluent;

producing micro-organic biomass from said fiber effluent and fiber liquor; and

feeding fishes with the micro-organic biomass produced with said fiber effluent.

3. A method according to claim 1 further comprising the step of producing micro-organic biomass from the excreta of said animals as feed for said fishes.

4. A method according to claim 1 or 2 wherein excreta produced by said animals is further separated into liquid excreta and solid excreta, said solid excreta fed directly to said fishes in at least one said fish pond, said liquid excreta used for producing micro-organic biomass as feed for said fishes.

5. A method according to any one of claim 1-4 wherein effluent from said fish pond is discharged into an oxidation pond.

6. A method according to claim 3 or 4 wherein micro-organic biomass production using excreta further comprises aerobic bacterial, fungal and protozoan growth in an aerated lagoon.

7. A method according to claim 1 or 2 wherein said micro-organic biomass production step further comprises a first stage and a second stage, said first stage includes bioremediation by fungi or bacteria, said second stage includes the production of protozoa from feeding of said fungi and bacteria.

8. A method according to any one of claim 1-4 wherein said fishes are further processed into fish meal.

9. A method according to any one of claim 1-4 wherein said fishes are further processed into fish meal, and the waste water produced during the fish meal production is discharged into an aerated lagoon for micro-organic biomass production.

10. A method according to claim 2 wherein said micro-organic biomass produced from said fiber effluent is produced by growth in an aerated lagoon.

11. A method according to claim 3 or 4 wherein biomass production using excreta further comprises micro-organic growth in an aerated lagoon, such that the soluble BOD of said aerated lagoon is below 75 mg/L before being discharged into said fish pond.

12. A method according to any one of claim 1-4 wherein biomass production using sludge liquor comprises yeast or bacterial fermentation.

13. A method according to any one of claim 1-4 wherein biomass production using sludge liquor further comprises yeast or bacterial fermentation in a bioreactor.

14. A method according to any one of claim 1-4 wherein biomass production using sludge liquor further comprises yeast fermentation in a bioreactor, whereby the soluble BOD is reduced to below 75 mg/L before effluent from said bioreactor is discharged into said fish pond.

15. A method according to any one of claim 1-4 wherein said sludge solid is dewatered before being fed to animals.

16. A system for treating palm oil mill effluent comprising :

means for pressing said palm to produce crude oil and empty fruit bunches;

means for separating said crude oil into palm oil and sludge;

means for separating said sludge into sludge solid and sludge liquor;

means for converting said sludge liquor into micro-organic biomass;

animal raising facilities with animals for digesting said sludge solid; and

at least one fish pond with fishes for converting said micro-organic biomass into high value protein.

17. A system according to claim 16 further comprising :

means for converting excreta generated from said animals into micro-organic biomass.

18. A system according to claim 16 further comprising

means for receiving excreta produced by said animals;

means for separating said animal excreta into solid and liquid; and

means for converting said liquid excreta into micro-organic biomass;

and said fishes in at least one fish pond are further used to convert said solid excreta into high value protein.

19. A system according to claim 16 further comprising :

means for pressing said empty fruit bunches to produce fiber liquor and fibers;

means for rinsing said fibers to produce fiber effluent; and

means for producing micro-organic biomass from said fiber effluent.

20. A system according to claim 16 further comprising an oxidation pond for receiving and treating said effluent from said fish pond.

21. A system according to any one of claim 16-19 wherein said means for converting said sludge liquor comprises at least one yeast or bacterial bioreactor.

22. A system according to any one of claim 16-19 wherein said means for converting said sludge liquor comprises at least one yeast or bacterial bioreactor and an aerated lagoon.

23. A system according to claim 16 wherein said means for separating said sludge into sludge solid and sludge liquor comprises a sludge tank or a decanter system.

24. A system according to claim 17 wherein said means for converting said liquid excreta is at least one aerated lagoon.

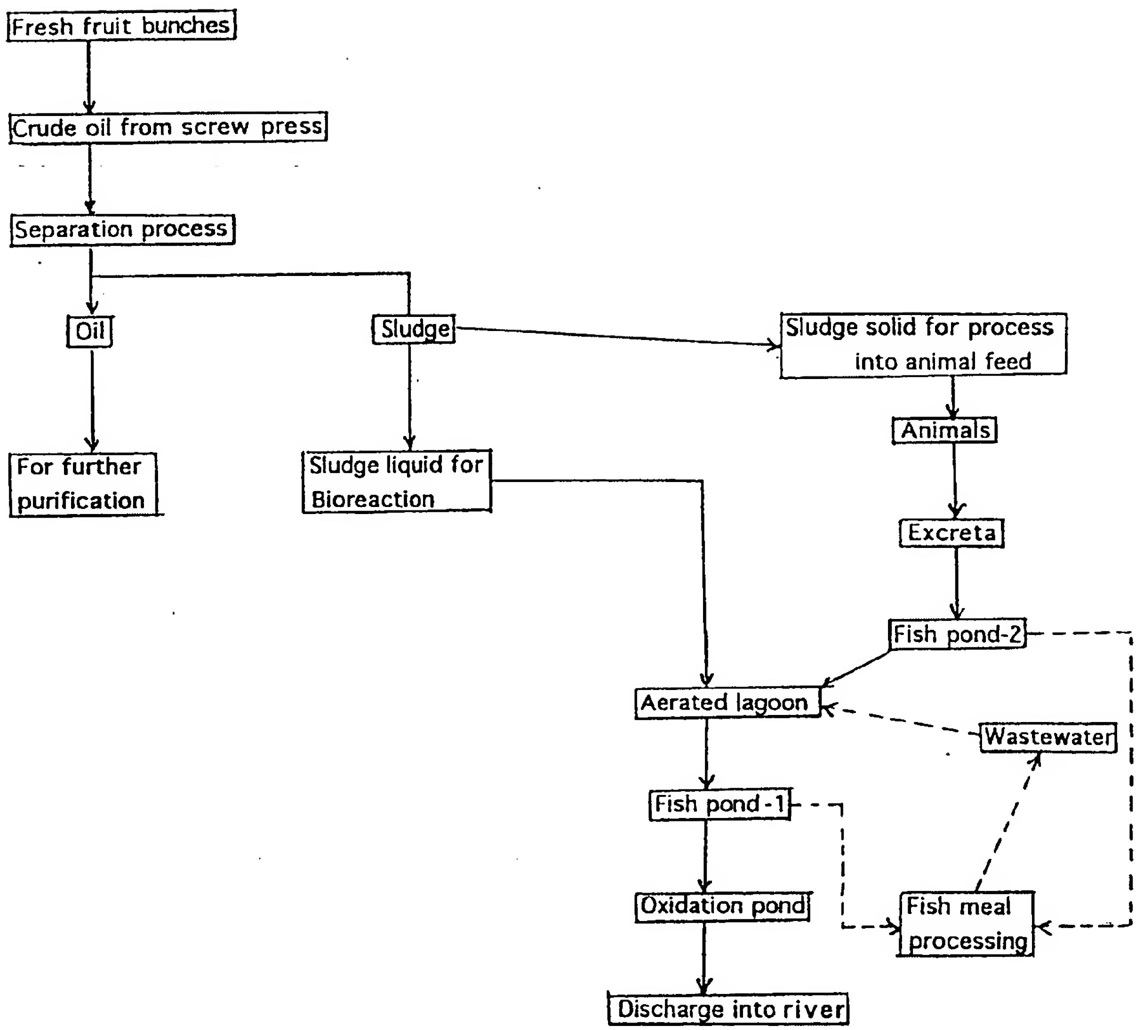

Fresh fruit bunches
Crude oil from screw press
Separation process
Oil
Sludge
Sludge solid for process into animal feed
For further purification
Sludge liquid for Bioreaction
Animals
Excreta
Fish pond-2
Aerated lagoon
Wastewater
Fish pond-1
Oxidation pond
Fish meal processing
Discharge into river

Fig.1

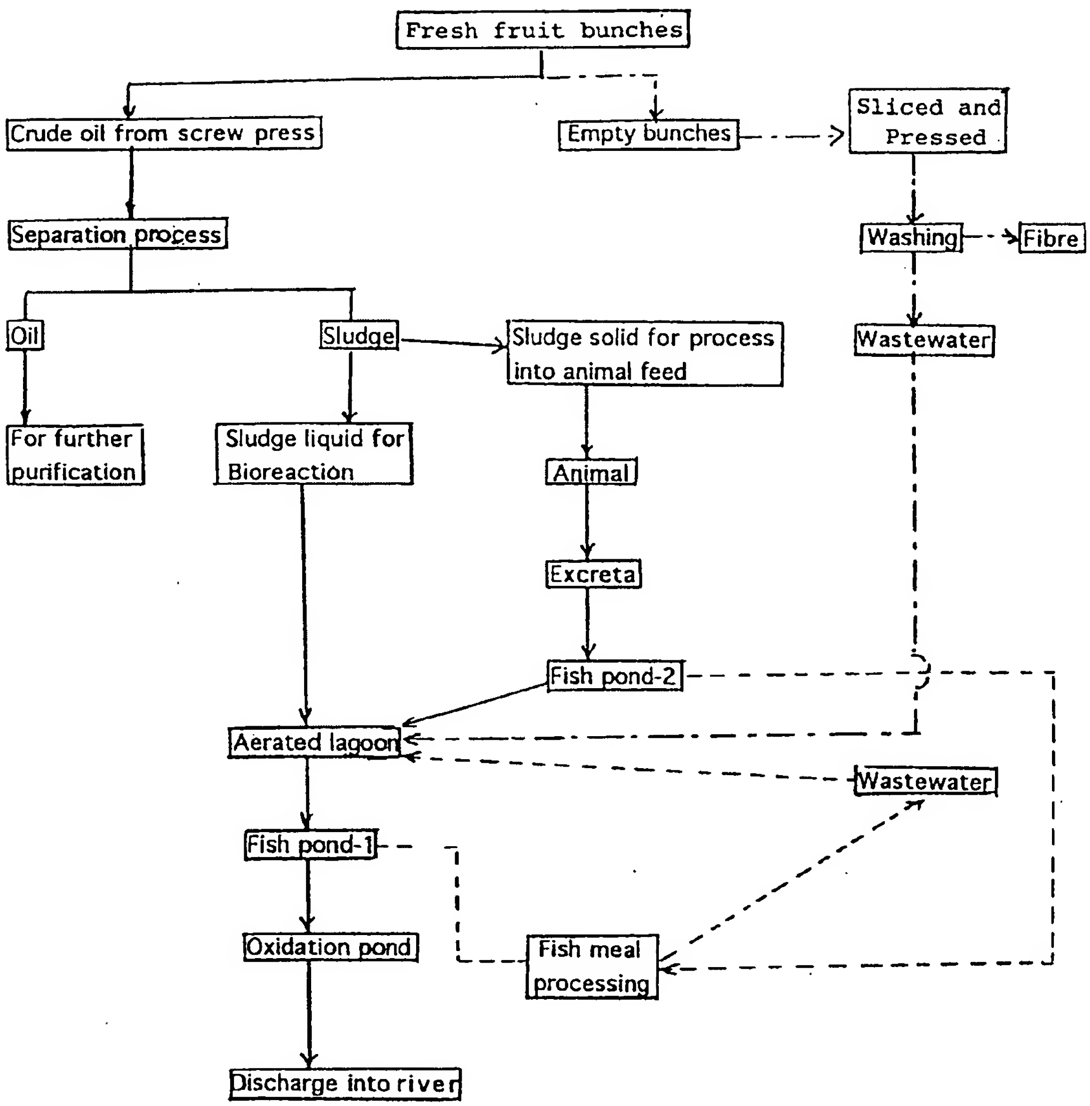
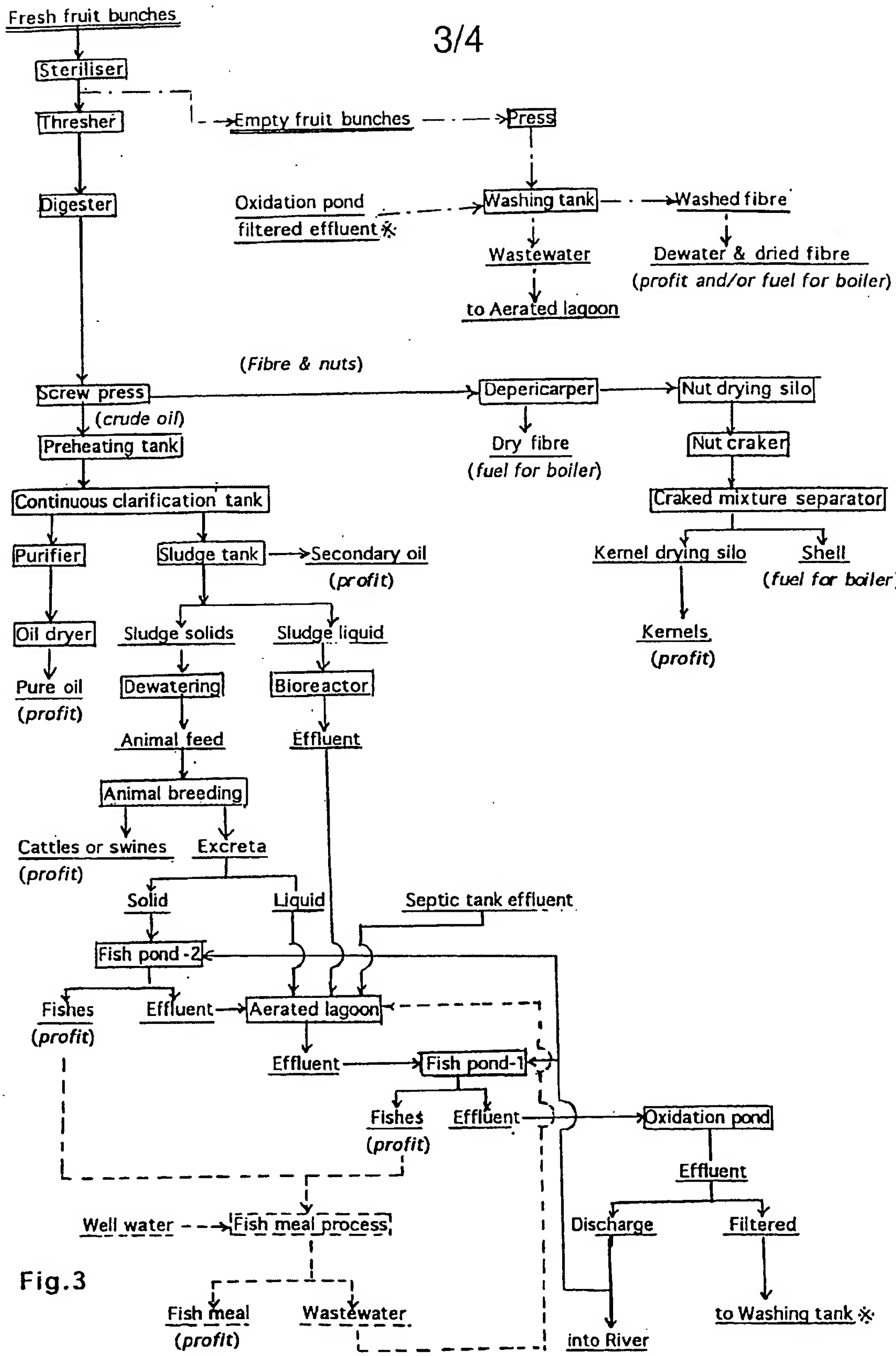

Fresh fruit bunches
Crude oil from screw press
Empty bunches
Sliced and Pressed
Separation process
Washing
Fibre
Oil
Sludge
Sludge solid for process into animal feed
Wastewater
For further purification
Sludge liquid for Bioreaction
Animal
Excreta
Fish pond-2
Aerated lagoon
Wastewater
Fish pond-1
Oxidation pond
Fish meal processing
Discharge into river

Fig.2



Fresh fruit bunches
Steriliser
Thresher
Empty fruit bunches
Press
Digester
Oxidation pond filtered effluent ※
Washing tank
Washed fibre
Wastewater
Dewater & dried fibre
(profit and/or fuel for boiler)
to Aerated lagoon
(Fibre & nuts)
Screw press
(crude oil)
Depericarper
Nut drying silo
Preheating tank
Dry fibre
(fuel for boiler)
Nut craker
Continuous clarification tank
Craked mixture separator
Purifier
Sludge tank
Secondary oil
(profit)
Kernel drying silo
Shell
(fuel for boiler)
Oil dryer
Sludge solids
Sludge liquid
Kernels
(profit)
Pure oil
(profit)
Dewatering
Bioreactor
Animal feed
Effluent
Animal breeding
Cattles or swines
(profit)
Excreta
Solid
Liquid
Septic tank effluent
Fish pond -2
Fishes
(profit)
Effluent
Aerated lagoon
Effluent
Fish pond-1
Fishes
(profit)
Effluent
Oxidation pond
Effluent
Discharge
Filtered
Well water
Fish meal process
Fish meal
(profit)
Wastewater
into River
to Washing tank ※

Fig.3

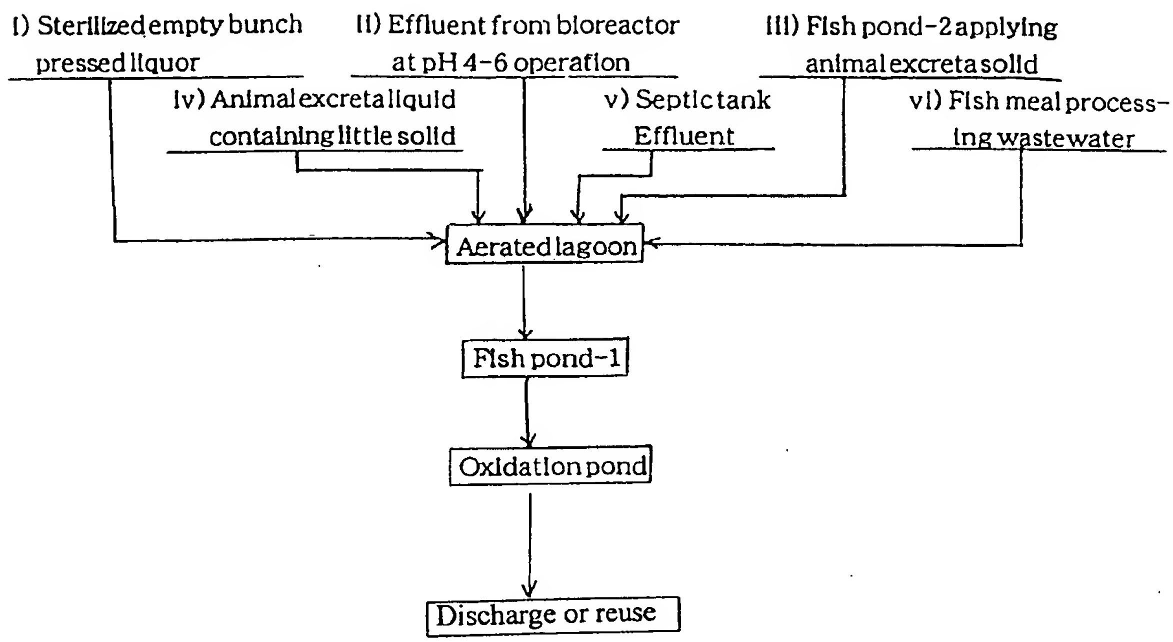

i) Sterilized empty bunch pressed liquor
ii) Effluent from bioreactor at pH 4-6 operation
iii) Fish pond-2 applying animal excreta solid
iv) Animal excreta liquid containing little solid
v) Septic tank Effluent
vi) Fish meal processing wastewater
Aerated lagoon
Fish pond-1
Oxidation pond
Discharge or reuse

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG00/00003

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: C02F 11/02, C11B 13/00, A23K 1/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: as above

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT & JAPIO; keywords: palm oil, sludge

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2007205A (ALFA-LAVAL AB) 16 May 1979 See page 2 line 68 - page 3 line 8 and claims 15-17	1-24
X	GB 2023120A (THE UNIVERSITY OF MALAYA) 28 December 1979 See page 1 lines 74-110 and Examples 2 and 4	1-24
X	GB 2023118A (AJINOMOTO CO.) 28 December 1979 See page 1 lines 79-98 and Examples 1-3	1-24

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 13 March 2000	Date of mailing of the international search report 22 MAR 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer ALBERT S. J. YONG Telephone No : (02) 6283 2160

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG00/00003

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 1601350A (ASAHI DENKA KOGYO KK) 28 October 1981 See page 2 lines 10-51	1-24
X	GB 1529934A (IMPERIAL CHEMICAL INDUSTRIES LTD) 25 October 1978 See page 1 lines 27-40, page 2 lines 28-50	1-24
X	GB 1521609A (WESTERN PACIFIC WATER TREATMENT CORP.) 16 August 1978 See page 1 line 34 - page 2 line 63	1-24
A	US 5039455A (KOOL) 13 August 1991 See column 11 lines 8-12	1

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG00/00003

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
GB	**2007205**	NONE			
GB	**2023120**	PH	20878		
GB	**2023118**	JP	54141054	MY	43/84
GB	**1601350**	JP	54012148	MY	901/85
GB	**1529934**	BR	7706400		
GB	**1521609**	AU	20321/76	MY	237/84
US	5039455	NONE			
					END OF ANNEX